Pioneer Mission Support

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The Deep Space Network (DSN) is preparing for the tracking and data acquisition support of Pioneers F and G. The major objective is to produce an effective data return capability from the vicinity of Jupiter. This report describes the spacecraft's internal data flow design and identifies the interfaces between the spacecraft and the DSN data system. This report is a continuation of two previous papers which delineated the mission profiles and spacecraft design.

I. Introduction

The Deep Space Network is preparing for the tracking and data acquisition support of the *Pioneer F/G* missions. *Pioneer F* will be launched at the end of February, 1972, and *Pioneer G* 14 months later. Both missions are designed to investigate the interplanetary medium, to explore the hazards on the asteroid belt and increase our knowledge of the solar system's largest planet, Jupiter.

The first two parts of this report were published in Refs. 1 and 2. The first part described the *Pioneer F/G* mission profile, spacecraft system, electrical power supply, thermal control and attitude control. The characteristics of these missions which interface with the tracking and data acquisition functions were delineated. The second part described the telecommunications, antenna and Conscan subsystems. The objective of this report is to provide the reader some insight into the spacecraft internal data flow design by presenting a description of the data handling and command subsystems.

II. *Pioneer F/G* Data Handling Subsystem

The spacecraft's data handling subsystem processes data originating from two major data sources: The first group of data is obtained from the outputs of the eleven onboard scientific instruments which provide data on the scientific measurements, configuration status, and operational health. The second group of data is composed of engineering data collected from sensors and transducers furnishing information necessary to determine spacecraft configuration status, operational characteristics, and operational health.

The data handling subsystem has special capabilities of formatting and time-division multiplexing the data into a coded or uncoded serial type of data stream suitable for modulating the spacecraft's telemetry transmitter. Timing and operational signals are also provided to be included in the science and engineering data blocks. The data-handling subsystem can store and provide time-delayed readout of formatted data upon command request. The data handling subsystem consists of a digital telemetry unit, a data storage unit, and a convolutional coder which is an integral part of the digital telemetry unit (Fig. 1). The data-handling subsystem has three operational modes, eight commandable bit rates from 16 to 2048 bits per second in binary increments and eleven data formats with 23 format combinations.

The three operational modes are: (1) real-time, (2) telemetry store, and (3) memory readout. In the *real-time mode* the data are transmitted directly without interim storage. In the *telemetry storage mode* the data are stored and transmitted simultaneously until the data storage unit is full. Then, at this time, the mode reverts automatically to a real-time mode at the last commanded format and bit rate. In this mode, it is possible to sample and store data at a more rapid rate than can be received on the ground. Then, the stored data can be transmitted later at the prevailing bit rate. The *memory readout mode* consists of transmitting the data stored in the memory at any selected bit rate. Figure 2 shows the interrelationship between the real-time and the telemetry storage modes and the flow of the controlling commands necessary to operate the spacecraft in these modes.

The data handling subsystem processes 88 analog, 76 digital, and 168 bilevel data input channels originating from science and engineering type data sources. The telemetry formats generated by the data-handling subsystem are divided into science and engineering groups. The science group includes two basic science formats and three special-purpose science formats for science main frame data, and two science formats that are subcommutated in the main frame. The basic science format contains 192 bits which includes 144 bits assigned to the scientific instruments, 6 bits to subcommutate the engineering formats, 6 bits to subcommutate the science subframe, 18 bits for frame synchronization and the remainder for identification of subcommutated data, telemetry mode, bit rate, and format. The basic science format word length is three bits. If higher resolution is required, two or three of these words are assigned. All of the basic science formats will be arranged for use primarily during interplanetary flight and the other during Jupiter encounter. In addition, three special-purpose science formats each contain 192 bits of digital data from only one or two scientific instruments, and are transmitted only in conjunction with one of the basic science formats alternating every 192 bits. These special formats provide the capability to sample data from certain scientific instruments at the high rate at the expense of reducing the amount of data from other instruments by one half. This feature will be particularly useful when the spacecraft is in the vicinity of Jupiter.

The typical *Pioneer F/G* formats are: A, B, C-1 through 4, A/D-1 through 8, B/D-1 through 8.

Telemetry Format A is the first science format that is arranged to meet the scientific requirements during interplanetary cruising. Figure 3 describes briefly these typical formats. All forty-three 3-bit words available are assigned to the scientific instruments for the *Pioneer F* mission. Seven scientific experiments share this format. The first 3 bits of each main frame contain the mode identification information. These words indicate whether the spacecraft is operating in the real-time, memory readout, or telemetry store modes. Bits 4 to 6 identify the spacecraft bit rate of 16 to 2048 bits per second in binary increments. Bits 8 through 24 comprise an 18-bit-long frame synchronization word. This word is standard in all *Pioneer* telemetry frames and is used by the ground data processing equipment to synchronize the received telemetry frames and words. Bits 97 through 101 are used for format identification. The subcommutation identification is represented by a 7 bit-word, bits 102 through 108 of each main frame. Bit 102 is the most significant bit for the 128-word engineering subcommutator with the most significant bit first. The subcommutated engineering words are contained in bits 109 through 114.

These 6-bit words appear in 128 successive formats and are obtained from various spacecraft engineering instrumentation such as voltage and current monitors, and switch positions. Analog, digital and status information are also included in the engineering subcommutator words. The same engineering subcommutator is also used to telemeter the time necessary for correlating the attitude of the roll index reference line with science and engineering data. The command number and the stored execute delay time of five stored commands are also made available for ground validation and analysis purposes. The sequence status of the spacecraft's attitude-control system and the roll reference source and scientific instruments roll index pulse are also identified and telemetered. Additional engineering subcommutator words are available to transmit information on the star location, on the pulse length of the hydrazine thruster impulses, on the spin period sector generator modes, and on the power status of the control electronics assembly. The science subcommutator is also provided in each main frame consisting of sixty-four 6-bit words. The science subcommutator appears in bits 115 through 120 of the main frame. Analog, digital, and status information is accepted by the digital telemetry unit (DTU) from the scientific instruments for telemetering in the science subcommutator.

The format B is a second science format and is arranged to meet the scientific requirements during Jupiter encounter. It consists of an engineering subcommutator accelerated at the main frame-rate, resulting in a 32:1 sampling increase of the measurements. This high-time resolution engineering format will be used to investigate the engineering performance of the spacecraft or determine the source and cause of any detected anomaly. Format C has four basic types providing information on the four major engineering subsystems. C-1 is used for power, C-2 for the communications, C-3 for the electrical distribution/propulsion and C-4 for the attitude control subsystems. Formats D-1 through D-8 are special formats with the main frame of 192 bits. These mainframes are assigned to a single instrument with the exception of format D-2, in which two instruments share the format. A format-D can be telemetered only by alternating it with the frame of formats A or B.

The digital telemetry unit is the heart of the data-handling system and converts the time-multiplexed science and engineering data into a single data stream which modulates the spacecraft's transmitter. Nearly all elements of this unit are redundant. A stable, crystal-controlled 65.536 kHz clock and countdown chain will generate the timing signals needed throughout the spacecraft, and will transfer data to the digital telemetry unit. The roll index pulse generated by the attitude-control system referenced to the timing signals is used to produce accurate roll position signals. This determines the roll position of the on-board instruments in relation to both the data and the spin rate. The digital telemetry unit drives the transmitter with a serial bit stream in the NRZ-L form. This is by-phase modulated on a 32.768 kHz squarewave subcarrier.

The data storage unit (DSU) of the data-handling subsystem consists of a core stack containing 49,152 bits (or 256 streams of data) and associated logic. This unit, which is not redundant, has a read/restore type memory making possible the retransmission of stored spacecraft generated data. It is not necessary to clear the unit before starting a recording cycle. The storage and read-out of data need not be continuous, since they may be interrupted and continued later by command, if required.

The convolutional coder unit codes the format of the data from the digital telemetry unit or the data storage unit to increase the overall efficiency of the telemetry system. The telemetry data can be either coded or uncoded by command. Figure 4 shows the functional configuration of the coder. The main element of this device is a multiple-bit shift register in which the data are shifted in and out of the register at the data bit rate. The encoder replaces each data bit generated by the digital telemetry unit by two symbols, P and Q. The value of each symbol is based on the values of 32 selected data bits previously generated. Each PQ is a logical "1" if there are an odd number "1's" in the selected data bits; otherwise it is a logical "0". The encoding cycle begins at the end of the last bit of each frame synchronization word at which time each stage of the shift register containing the value of the previously transmitted 32 data bits and the 33rd flip-flop used to generate the code are reset to a logical "0". The output symbol rate of the encoder is double that of the input data rate. In error-free data, the bits of a pair provide an unambiguous representation of the original data bit. With errors in the data, the decoding process performed at the deep space stations utilizing the sequence of PQ will provide reconstructed error-free data for transmission conditions well beyond normal acceptable limits without the coding. An overall coding gain of between 3.5 to 4 dB is expected.

III. *Pioneer F/G* Command Subsystem

The spacecraft's command subsystem provides the capability of controlling the operating modes of the spacecraft equipment and scientific instruments from information received from the RF transmissions of the deep space stations and from signals generated on board at discrete events. The command subsystem consists of two command decoders and a command distribution unit (Fig. 5).

The commands are transmitted to the spacecraft by the DSN station having a PCM/FSK/PM modulation of the uplink S-band carrier signal and employing a rate of 1 bit/sec. Twenty-two bits are transmitted from the ground for a single command message. Table 1 illustrates the twenty-two command bits. After a 4-bit preamble and a 1-bit sync pulse, 2 bits are used for selecting a decoder, 3 bits are used for command routing within the spacecraft, and 8 bits contain the command information. The last 4 bits comprise a priority check word. The code used is an optimal Hamming-type linear block code capable of detecting all possible 1- and 2-bit error patterns. The modulo-2 summation of the selected routing and data bits results in even parity for each case.

The bit error rate of the ground system is 10^{-5}. By applying the described command block code, the combined spacecraft/DSN system word error rate has been increased to 10^{-9}. The activated spacecraft receiver demodulates the S-band carrier and provides the frequency shift key tones (FSK) to the command decoders. The 128 Hz represents a "0" and 204.8 Hz represents a "1". The addressed decoder converts the FSK tones to digital data and performs a verification operation with the command message to reduce the probability of executing wrong commands. The decoder forwards the routing address, command message, and if the command is properly verified, an execute pulse to the command distribution unit. If the command is not properly verified by the decoder, the execute pulse is inhibited and the command distribution unit does not act upon the command message.

The command distribution unit processes and distributes all commands to the spacecraft equipment and scientific instruments. Two basic types of output are provided by the command distribution unit: The first is a serial data output to a specific user; the routing portion of the command message identifies the user, and the 8 bits of command information provide the serial data. The second output is a signal applied to any one of the 255 discrete lines for initiating specific functions. The routing portion of the message signifies this discrete type of output and the 8-bit command information identifies the particular one of the possible 255 discrete commands. The command distribution unit also has the capability of being programmed by the routing and command messages to store up to 5 discrete commands for sequential execution at a later time and to store the time delay between sequence enable and sequence execution, and between each command of the sequence. This feature permits the command to be sent and verified by telemetry before execution and will be particularly useful when the communication round-trip time is great. In addition, the command distribution unit will provide a sequence of commands that will be activated at preset intervals by a sequencer which will be initiated automatically by separation of the spacecraft from the launch vehicle.

For redundancy, two decoders are provided for selective operation by an address in the transmitted command message. Redundant paths are provided throughout the logic of the command distribution unit. The discrete outputs are wired to prevent single-part failures from activating other outputs.

The spacecraft is capable of receiving continuous strings of commands by receiving one or more zeros between each adjacent command. Thus, it is possible to reduce the command word lengths to 19 bits for all except the first command.

IV. *Pioneer F/G* Scientific Investigations

Eleven of the scientific investigations that will be conducted by the *Pioneer F/G* program utilize specialized scientific instruments on the spacecraft. However, two investigations use only Earth-based equipment and the S-band communication signal between the spacecraft and the stations of the DSN.

Table 2 shows a listing of the scientific objectives of the thirteen scientific investigations.

References

1. Siegmeth, A. J., "*Pioneer* Mission Support," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. II, pp. 6–17. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.

2. Siegmeth, A. J., "*Pioneer* Mission Support," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. III, pp. 7–19. Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1971.

Table 1. *Pioneer F* and G command word

Bit numbers	Bits	Function
1—4	0 0 0 0	Preamble
5	1	Sync
6, 7	A_1 A_2	Decoder address
8—10	R_1 R_2 R_3	Routing address
11—18	C_1 C_2 C_3 C_4 C_5 C_6 C_7 C_8	Command message
19—22	P_1 P_2 P_3 P_4	Parity checks

Decoder addresses are 01 or 10 only.
Parity bits are generated as follows:

$$P_1 = R_1 + R_2 + R_3 + C_1 + C_2 + C_3 + C_4$$
$$P_2 = R_1 + R_2 + R_3 + C_1 + C_6 + C_7 + C_8$$
$$P_3 = R_1 + R_2 + C_2 + C_3 + C_5 + C_6 + C_7$$
$$P_4 = R_1 + R_3 + C_2 + C_4 + C_5 + C_6 + C_8$$

Table 2. *Pioneer F and G experiments*

Scientific objectives	Instrument or function (principal investigator)												
	Three-axis magnetometer (E. J. Smith)	Plasma analyzer (J. H. Wolfe)	Charged particle telescope and detector (J. A. Simpson)	Geiger-Muller telescope system (J. A. Van Allen)	Cosmic-ray telescope (F. S. McDonald)	Trapped radiation detector (R. W. Fillius)	Ultraviolet photometer (D. L. Judge)	Imaging photopolarimeter (T. Gehrels)	Two-channel infrared radiometer (G. Munch)	Asteroid/meteoroid nonimaging telescope (R. K. Soberman)	Meteoroid detector (W. H. Kinard)	S-band occultation (A. J. Kliore)	Celestial mechanics (J. D. Anderson)
Interplanetary													
Solar plasma		√			√								
Solar and galactic cosmic rays			√	√	√								
Shock waves			√										
Neutral hydrogen							√						
Magnetic fields	√												
Particulate matter								√		√	√		
Asteroid belt													
Solid particle flux								√		√	√		
Asteroid surface properties								√					
Mass properties and velocities										√			
Particle size										√	√		
Particle distribution								√		√	√		
Particle surface properties								√					
Jupiter													
Bow shock and magnetosphere boundary	√	√	√	√	√	√							
Electr. prot. in magnetosphere	√	√	√	√	√	√							
Mag. field & source charact.	√	√	√	√	√	√							
Trapped radiation belts	√		√	√	√	√							
Origins of radio emissions	√		√	√	√	√							
Location of dayside aurora							√						
Gross structure of ionosphere												√	
Temperature of upper atmosphere							√						
Atmos. hydrogen-helium ratio							√		√			√	
Temp. distrib. in outer layers of atmos.									√				
Gross structure of atmosphere												√	
Comp. variations in clouds								√	√				
Cloud structure								√	√				
Bright. temp. of dark hemisphere									√				
Jovian polar ice cap									√				
Inter. emergy rad. from Jupiter									√				
Jupiter mass & grav. field harm.									√				
Heliocentric orbit of Jupiter													√
Jovian satellites													
Gross surface characteristics								√					
Mass and orbits													√
Solar galactic boundary													
Magnetic structure	√												
Particle characteristics		√			√		√						
Interstellar space													
Cosmic-ray density			√	√	√	√							

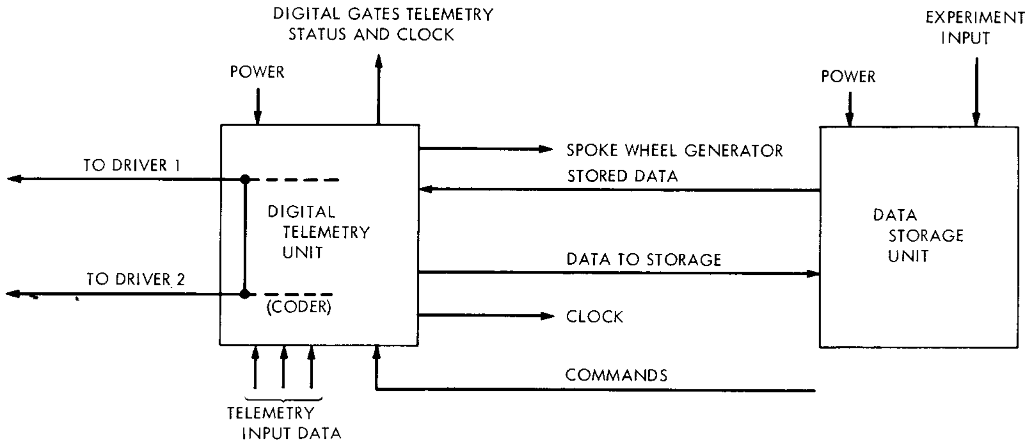

Fig. 1. *Pioneers F and G data-handling subsystem*

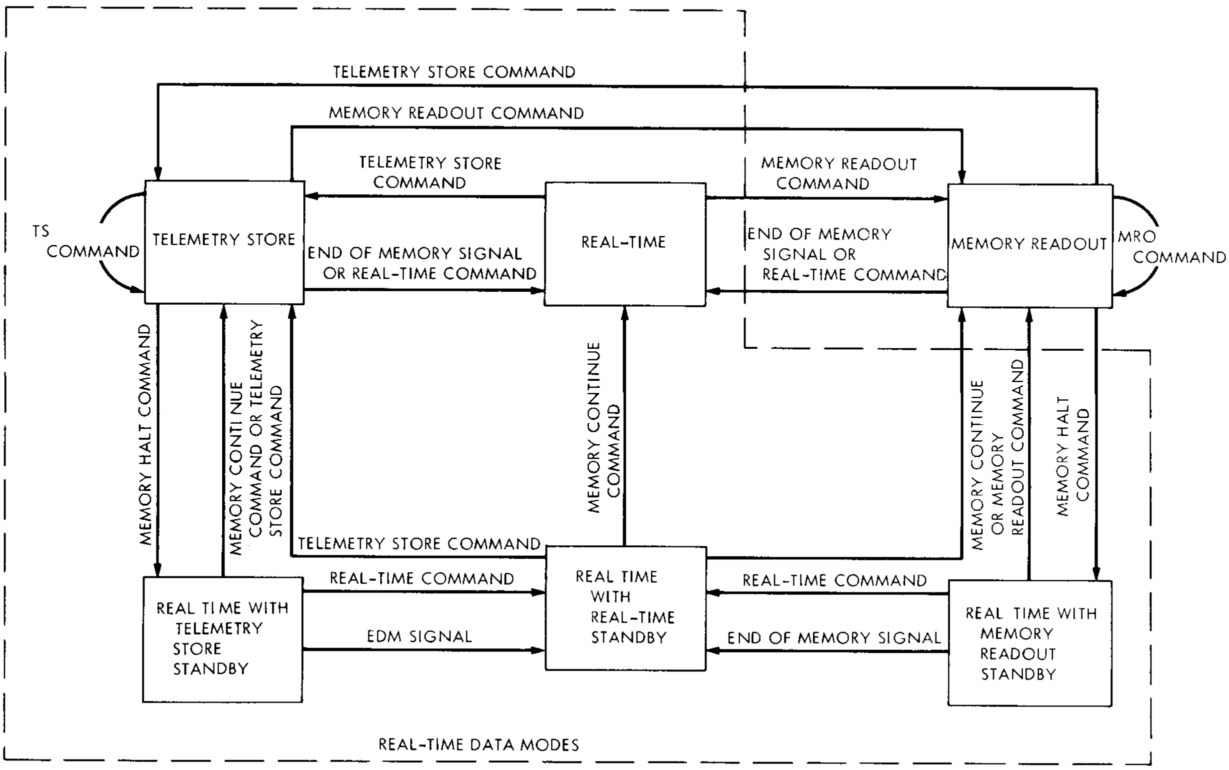

Fig. 2. *Pioneers F and G spacecraft data system modes*

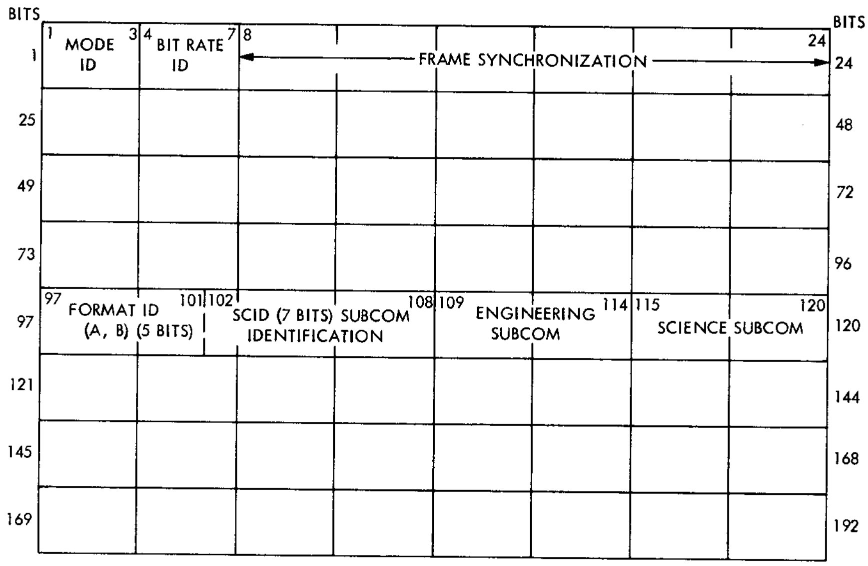

Fig. 3. ***Pioneers F and G telemetry format A***

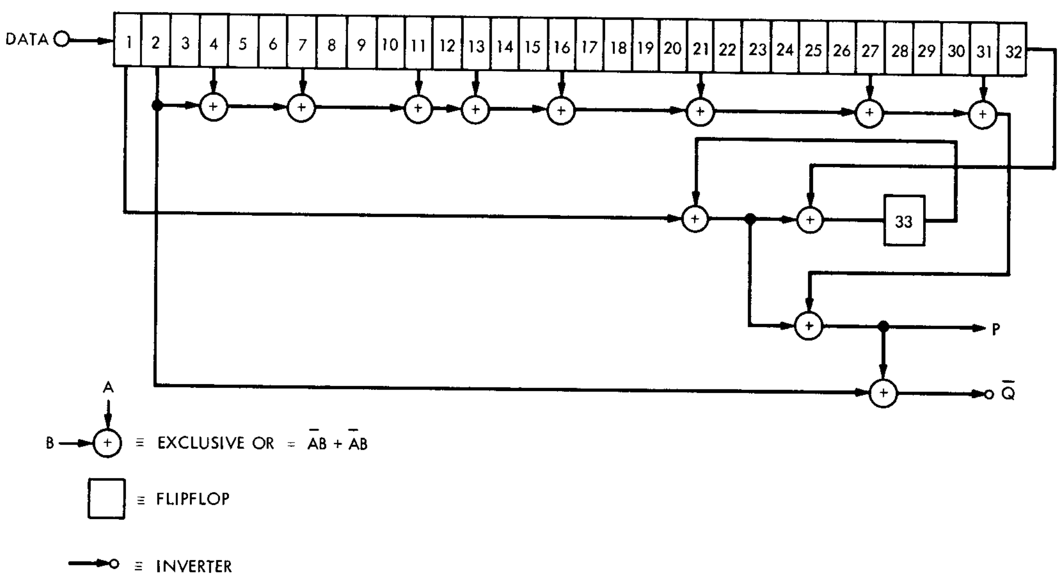

Fig. 4. ***Pioneers F and G convolutional coder***

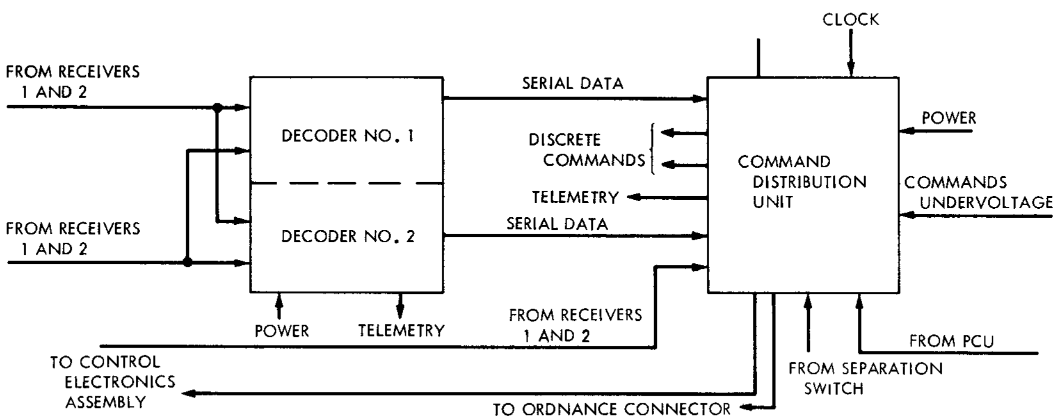

Fig. 5. ***Pioneers F and G command subsystem***